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PRINT FIG. 1(b)

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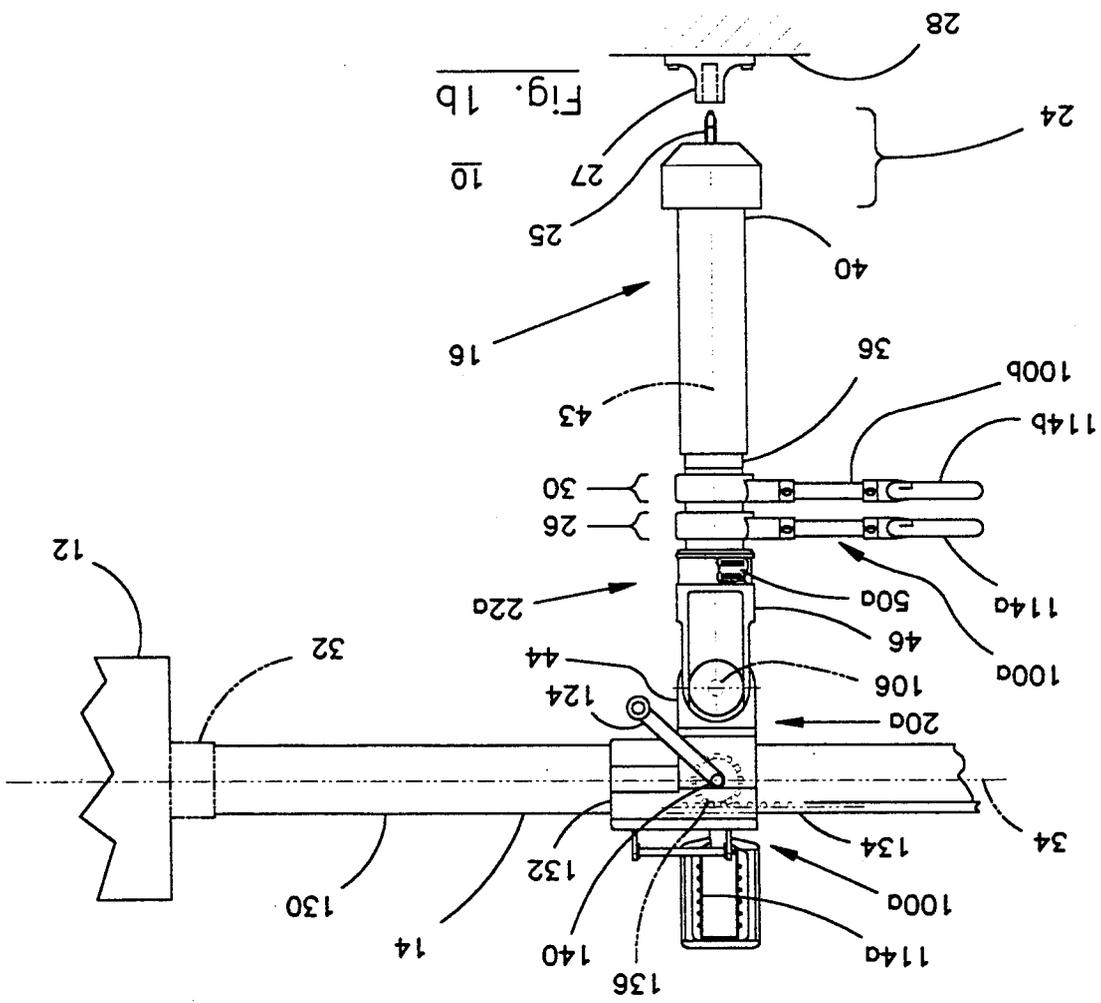


Fig. 10

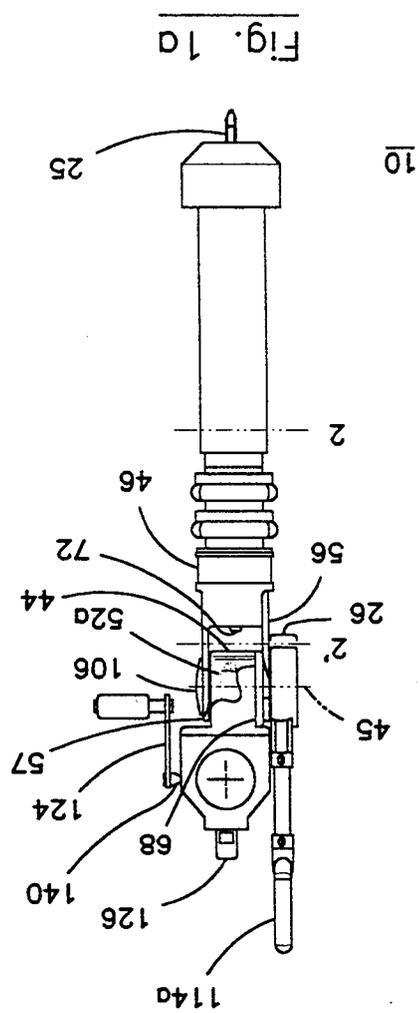


Fig. 10a

10

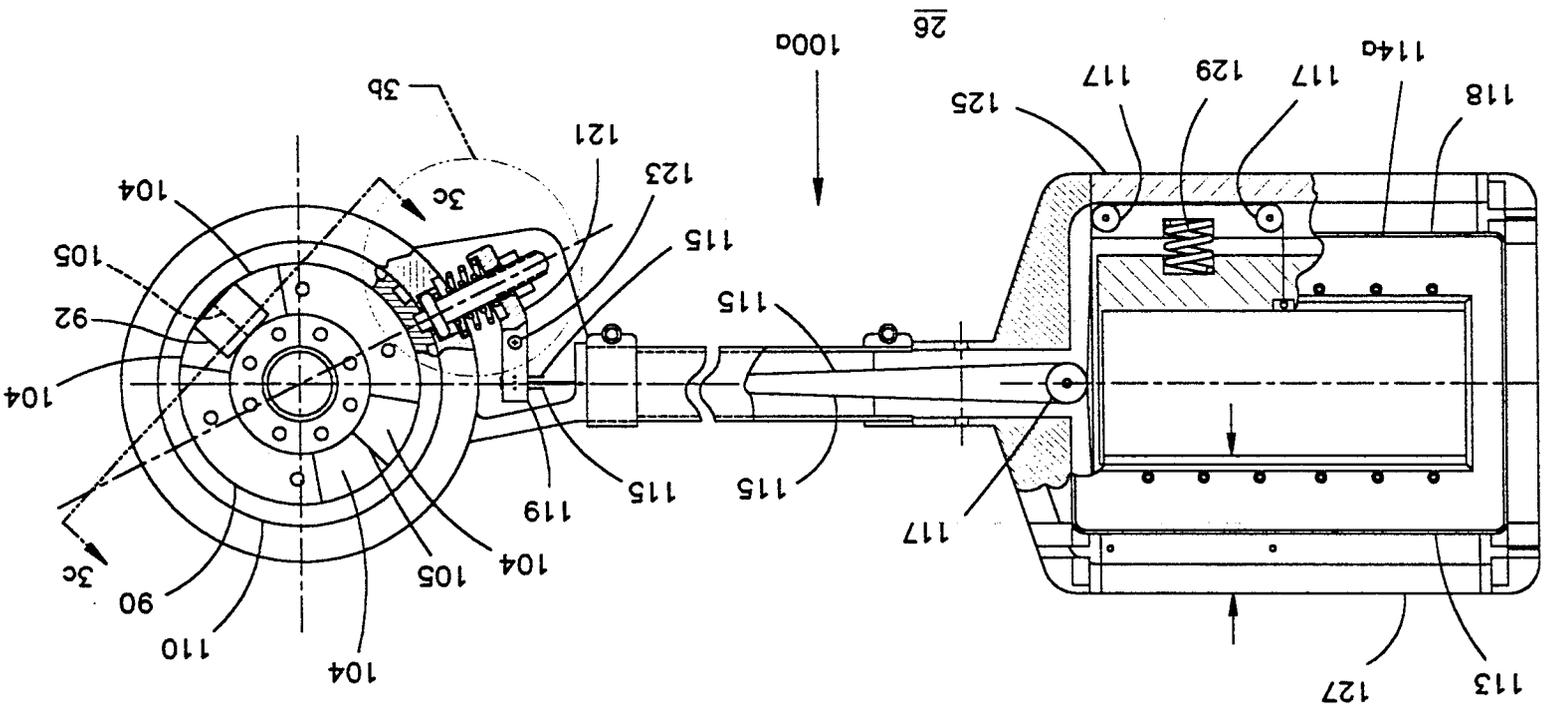


Fig. 3a

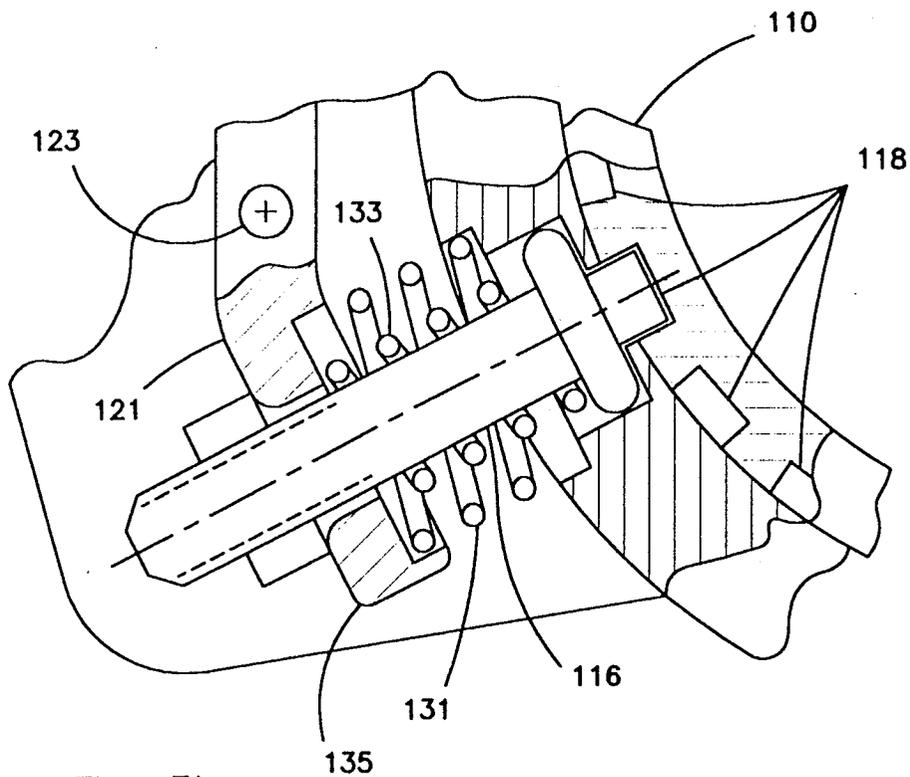


Fig. 3b

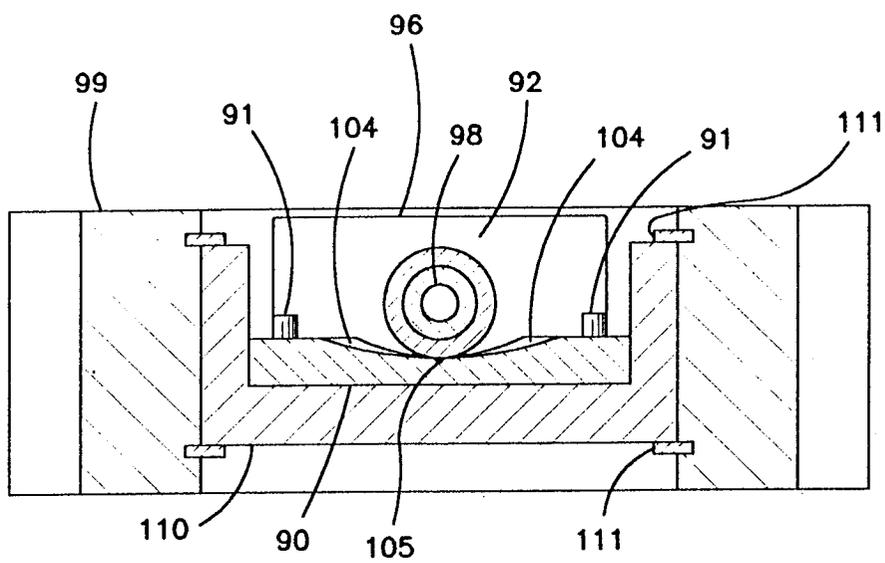


Fig. 3c

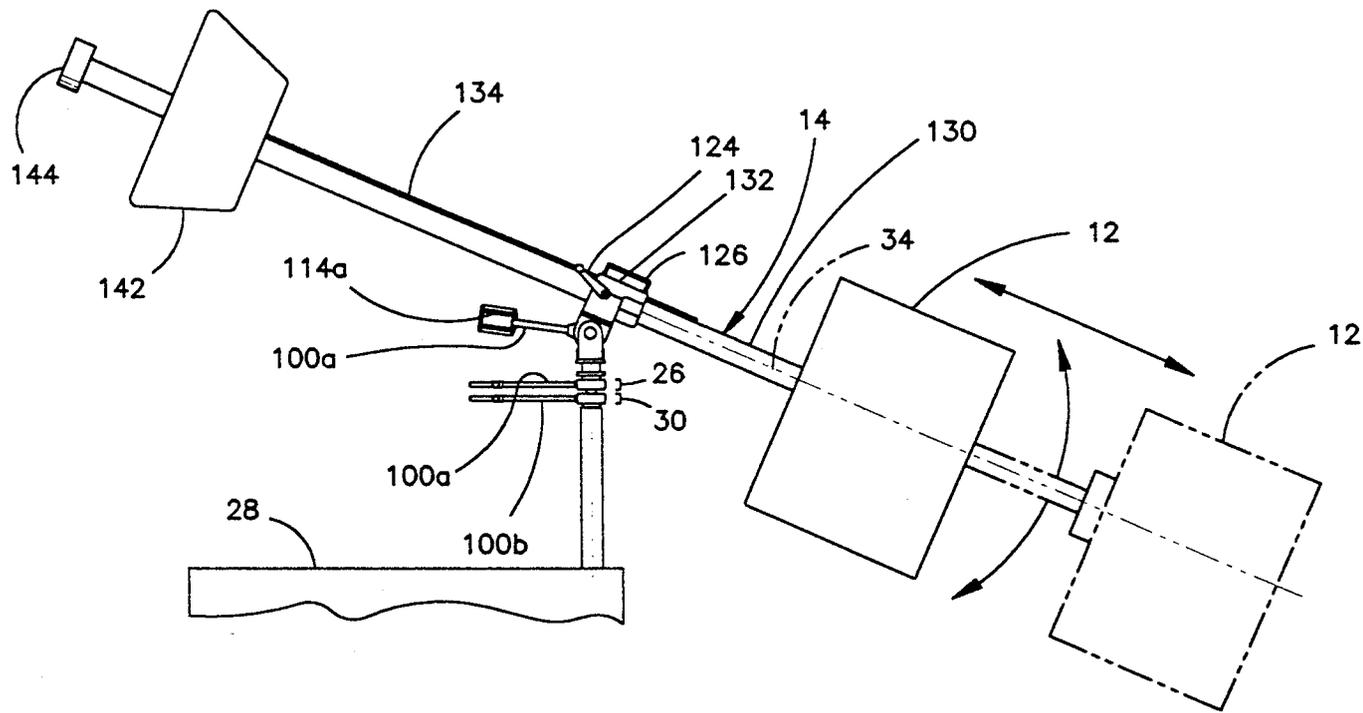


Fig. 4

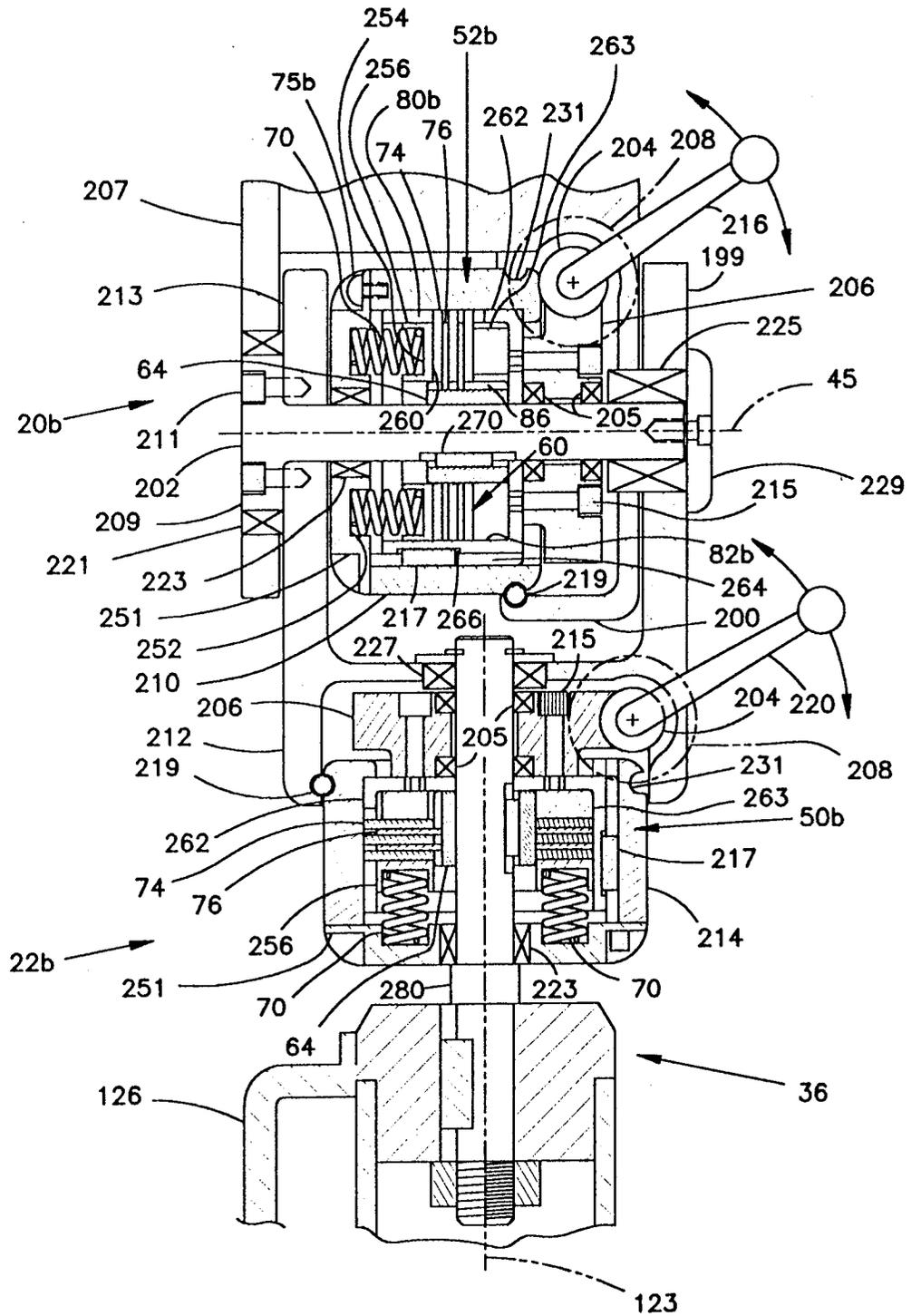


Fig. 5

TORQUE-LIMITING MANIPULATION DEVICE**Origin of the Invention**

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National
5 Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

Field of the Invention

This invention relates to a device for manipulating a workpiece attached to a boom assembly, and, more particularly, to a device which includes yaw and pitch
10 torque-limiting mechanisms which stabilize the boom assembly, and permits convenient manual control of a boom assembly about yaw and pitch axes by levers.

Background of the Invention

In many operations, particularly operations involving the manipulation and control of a bulky workpiece in two-dimensional or three-dimensional space, it is
15 sometimes difficult for a handicapped operator (e.g., a paraplegic, or a non-physically challenged person who is otherwise unable to use his or her legs due to icy conditions, etc.) to locate convenient points against which the operator may react the manipulation forces necessary to control the workpiece. As the workpiece, which the operator is to manipulate, moves, so too do the reaction points, thus making the task
20 of finding suitable reaction points more difficult and sometimes dangerous.

Accordingly, designers of equipment for paraplegic use have devised many alternative ways to permit the operator's hands to compensate for a lack of leg strength. However, these mechanisms are not designed to enable the operator to move, lift, and otherwise reposition bulky or heavy workpieces in a plane or in three-
25 dimensional space.

In addition, designers have designed extra-vehicular activity ("EVA") tools, for use in low-earth orbit spacecraft assembly operations, to eliminate or minimize the

which connects between the torsionally-yielding structural member and its associated torsionally-stationary structure. This arrangement enables frictional restraint of the boom assembly against free movement. The torsionally-yielding member is the housing of the corresponding joint. The torsionally-stationary member associated with
5 the pitch joint includes two support arms extending up from the yaw housing. The torsionally-stationary member associated with the yaw joint is the upper end of the stanchion assembly.

Each torque-limiting mechanism includes a torque-limiting clutch disk stack, a driving cup, a clutch hub, a pressure plate, a cover plate, biasing springs, and a shaft.
10 The torque-limiting clutch disk stack includes alternating first clutch disks and second clutch disks. The clutch disks have an inner aperture concentric with an outer circular perimeter. The first clutch disks have outwardly extending tabs, and the second clutch disks have inwardly extending tabs. The driving cup rigidly attaches to the torsionally-yielding member, and includes a relief cut in a sidewall of the driving
15 cup which receives the tabs of the first clutch disks. The clutch hub has an external keyway which receives the tabs of the second clutch disks. The pressure plate mounts in the torsionally-yielding member substantially coaxial with the clutch hub, permits limited axial motion, and prevents rotating motion with respect to the torsionally-yielding member. The biasing springs mount between the cover plate and the
20 pressure plate, thus exerting pressure on the disks of the stack. The shaft nonrotatably mounts to the clutch hub and to the stationary member. The cover plate attaches to the torsionally-yielding member, and closes the torque-limiting mechanism.

An advantage of the present invention is that it is simple to assemble and maintain. This is in part because the manipulation device is manually-driveable,
25 requiring few or no electronic components.

Another advantage of the present invention is that it is simple to operate, requiring only the use of the operators arms and hands.

Another advantage of the present invention is that it securely controls the workpiece during translation, thus minimizing flailing or other unwanted, and often unpredictable oscillation.

5 Another advantage of the present invention is that the workpiece is positionable anywhere in three-dimensional space, within the extension limits of the manipulation device, while the operator remains in one location.

Another advantage of the present invention is that, in the preferred embodiment, the operator may reposition the boom assembly (and therefore also the workpiece) in pitch and yaw without the operator otherwise being restrained, and, 10 consequently, this affords the operator greater mobility.

Another advantage of the present invention is that the manipulation device and the structure to which the manipulation device attaches are protected from large and potentially destructive forces input into the end of the boom assembly.

Brief Description of the Drawings

15 Fig. 1a is a partial cut-away, rear view of the preferred embodiment of the present invention.

Fig. 1b is a partial cut-way, side view of the preferred embodiment of the present invention.

20 Fig. 2 is a cross-sectional view of the yaw joint of the preferred embodiment of the present invention, taken between lines 2 and 2' in Fig. 1a.

Fig. 3a is a partial cut-way, top view of the actuation mechanism of the preferred embodiment of the present invention.

Fig. 3b is a detail view of the region of the invention identified in Fig. 3a.

25 Fig. 3c is a cross-sectional view of the invention taken along the line identified in Fig. 3a.

Fig. 4 is a side view of the preferred embodiment of the present invention in operation.

Fig. 5 is a partial cross-sectional view of the pitch and yaw joints of an alternate embodiment of the present invention.

Description of the Preferred Embodiment(s)

In Figs. 1a and 1b, a manipulation device 10 for manipulating a workpiece 12 in a plane or in three-dimensional space includes a boom assembly 14, a stanchion assembly 16, a pitch joint 20a and a yaw joint 22a, a mounting unit 24, actuation mechanisms 26, and a reaction mechanism 30. The boom assembly 14 includes an engaging mechanism 32 (shown in phantom) onto which the workpiece 12 affixes for translation along the axis 34 of the boom assembly.

The stanchion assembly 16 has an upper end 36 and a lower end 40. The pitch and yaw joints 20a and 22a connect the boom assembly 14 and the upper end 36 of the stanchion assembly 16.

The mounting unit 24 includes a probe 25 having a hexagonal cross-section. An upper end of the probe 25 nonrotatably affixes to the mounting unit 24, and a socket 27 receives a lower end of the probe 25. The socket 27 mounts to a structure 28.

The pitch and yaw joints 20a and 22a each include an actuation mechanism 26 whereby the boom assembly 14 moves about a pitch axis 45 or yaw axis 43. The reaction mechanism 30 includes a reaction lever assembly 100b against which the operator may react force inputs into the actuation mechanism 26, and which the operator may relocate about the yaw axis 43. The reaction mechanism 30 will be discussed in more detail below, in connection with Figs. 3a, 3b, and 4.

The pitch and yaw joints 20a and 22a each further include, respectively: a pitch housing 44 and a torque-limiting mechanism 52a; and a yaw housing 46, and a torque-limiting mechanism 50a. Each of the torque-limiting mechanisms 50a and 52a acts as a braking clutch, which enables frictional restraint of the boom assembly 14,

and prevents undesired movement when an object inadvertently disturbs the manipulation device 10. The housing 44 or 46 of the corresponding joint 20a or 22a, respectively, forms a torsionally-yielding member. Two support arms 56 and 57, extending up from the yaw housing 46, form a torsionally-stationary member for the pitch joint 20a. The upper end 36 of the stanchion assembly 16 forms a torsionally-stationary member for the yaw joint 22.

Now referring to Fig. 2, wherein according to the present invention, the torque-limiting mechanism 50a of the yaw joint 22a includes a torque-limiting clutch disk stack 60, a driving cup 62, a clutch hub 64, a pressure plate 66, a cover plate 68, biasing springs 70, a pressure disk 63, and a yaw shaft 72. The torque-limiting clutch disk stack 60 includes alternating first clutch disks 74 and second clutch disks 76. The clutch disks 74 and 76 each have an inner aperture concentric with an outer circular perimeter. The first clutch disks 74 have outwardly extending tabs 74' and the second clutch disks 76 have inwardly extending tabs 76'. The driving cup 62 rigidly attaches to the yaw housing 46, and includes a relief 80a cut in a sidewall 82a of the driving cup which receives the tabs 74' of the first clutch disks 74. The clutch hub 64 has an external keyway 86 which receives the tabs 76' of the second clutch disks 76. The pressure disk 63 mounts over the clutch hub 64. A retainer 81 mounts in a groove of the clutch hub 64. The retainer 81 retains the pressure disk 63 on the clutch hub 64 and against the clutch disk stack 60. The pressure plate 66 mounts in the yaw housing 46, and includes a disk-contacting surface 67 adjacent the disk stack 60, a flange portion 69 having annularly spaced-apart spring-receiving recesses 71, and a hub portion 73. The cover plate 68 affixes to the housing 46 via fasteners 75a, closes the torque-limiting mechanism 50a, and constrains the pressure plate 66 to axial translation in coaxial alignment with the clutch hub 64 and the pressure plate. The cover plate 68 further includes spring-receiving recesses 77 which correspond to

those of the pressure plate 66. Keyways 89 and 91 contain a key 88 between the pressure plate 66 and the cover plate 68, thereby preventing relative rotation between the pressure plate and the cover plate, yet permitting limited axial motion. Bushings 93 are disposed between the yaw shaft 72 and both the pressure plate 66 and a hub 5 96, for the purpose of reducing friction and decreasing wear. The biasing springs 70 mount within the spring-receiving recesses 71 and 77, between the cover plate 68 and the pressure plate 66, thus exerting pressure on the disks 74 and 76 of the stack 60. The yaw shaft 72 nonrotatably mounts to the clutch hub 64, and to the upper end 36 of the stanchion assembly 16, via keys 79. Bushings 65 are disposed between the yaw 10 housing 46 and the yaw shaft 72. A retaining ring 61 rotatably constrains the yaw shaft 72 against a shoulder 78.

The actuation mechanism 26 of the yaw joint 22a includes a cam ring 90, a cam follower 92, a thrust bushing 94, and a cam housing 110. The cam ring 90 rotatably mounts around the hub portion 73. The hub 96 affixes via fasteners 97 to 15 the hub portion 73. Pins 91 nonrotatably affix the cam ring 90 inside the cam housing 110, thus causing the cam ring to rotate with the cam housing. The cam follower 92 mounts on a follower pin 102 which radially receives in the hub 96. A bushing 98 mounts between the follower pin 102 and the cam follower 92.

The cam follower 92 rides against one of a pair of opposed helical ramps 104 20 (shown most clearly in Fig. 3c). The ramps 104 share a common edge 105 (shown in Fig. 3a) over which the cam follower 92 rests. The ramps 104 are integrally formed in the cam ring 90.

The thrust bushing 94 interposes between the cam housing 110 and the cover plate 68 for the purpose of reducing friction to a level that, when combined with the 25 friction between the cam ring 90, cam follower 92, and the follower pin 102, the total torsional-motion resistance which friction generates is less than a return torque. The

return torque generates after relative rotation of an actuation lever assembly **100a**, when the cam follower **92**, having rolled up the ramp **104** and thus having separated the disks **74** and **76** which bias together via the biasing springs **70**, attempts to return to its lowest energy state in which the cam follower **92** locates at the bottom of the ramps **104** wherein the rotational axis of the cam follower is parallel to the edge **105** (as depicted in Fig. **3a**) and the disks engage.

Referring again to Fig. **1a**, the torque-limiting mechanism **52a** and the actuation mechanism **26** of the pitch joint **20a** include identical items and functionally identical items, as compared to the yaw joint **22a**. In the pitch joint **20a**, the pitch shaft **106** and pitch housing **44** are functionally identical to the yaw shaft **72** and yaw housing **46**. The pitch shaft **106**, like the yaw shaft **72**, nonrotatably mounts to a clutch hub **64** and to a torsionally-stationary member, which, in this case, includes the two support arms **56** and **57**, extending up from the yaw housing **46**.

In addition, a cover plate **68** of the pitch joint **20a** axially restrains a pressure plate **66** (not shown, but identical to that in the yaw housing **22a**) of the pitch joint nonrotatably with respect to the corresponding housing **44** in the same manner as does the cover plate **68** of the yaw joint **22a**. The distinguishing difference between the pitch and yaw joints **20a** and **22a** is their orientation with respect to each other: the pitch shaft **106** affixes to the yaw housing **46** at a right angle to the yaw shaft **72**.

Referring again to Fig. **2**, the cam housing **110** interposes between the cam ring **90** and the thrust bushing **94**. A repositionable, normally unlocked, actuation lever assembly **100a** rotatably mounts over the cam housing **110**. Retainer rings **111** restrain the actuation lever assembly **100a** against axial movement with respect to the cam housing **110**.

Now referring to Fig. **3a** and **3b**, opposite sides **113** and **118** of an axially symmetrical hand-lever **114a** connect to cables **115**, which pulleys **117** direct, and

which affix to an end 119 of a bell-crank 121. The bell-crank 121 pivots on a pin 123. Springs 129 suspend the hand-lever 114a in a middle position, between two cross members 125 and 127. The bell-crank 129 includes a spring-biased pin 116 which passes through an aperture in an end 135 of the bell crank 121. Springs 131 and 133 suspend the pin 116 within the end 135. The cam housing 110 has divots 118 which the pin 116 engages when the operator depresses a cross member 125 or 127 against the adjacent side 113 or 118 of the hand-lever 114a. The engagement of the pin 116 into one of the divots 118 locks the actuation lever assembly 100a into the cam housing 110, thus preventing rotation of the lever assembly. When the operator releases the hand-lever 114a of the lever assembly 100a, the pin 116 disengages the divot 118, thus permitting the lever assembly 100a to be freely repositioned.

Now referring to Fig. 2, the reaction mechanism 30 includes a reaction hub 120, and the reaction lever assembly 100b. The reaction hub 120 affixes to the upper end 36 of the stanchion 16, and is positioned about the yaw axis 43 in a spaced-apart relationship to the yaw actuation mechanism 26. The reaction lever assembly 100b is repositionable, and normally unlocked. The reaction lever assembly 100b rotatably mounts over the reaction hub 120. Retainer rings 111 restrain the reaction lever assembly 100b against axial movement with respect to the reaction hub 120. The reaction hub 120 has divots 118 which are engaged by a spring-biased pin 116 in an identical manner as the pin 116 of the actuation mechanism 26, depicted in Figs. 3a and 3b, and described above.

Now referring to Fig. 4, in operation, the boom assembly 14 longitudinally projects and withdraws along axis 34 when an operator rotates a boom extension/retraction crank 124, and reacts against a handle 126 located on the boom assembly or against the reaction lever assembly 100b.

Actuating one of the actuation lever assemblies 100a against the reaction lever

assembly 100b adjusts the azimuth or elevation of the boom assembly 14. The actuation lever assemblies 100a rotatably move the boom assembly 14 about the yaw axis 43 and the pitch axis 45, and release respective torque-limiting mechanisms 50a and 52a, transmitting yaw and/or pitch inducing force to the boom assembly 14 through the reaction mechanism 30. The reaction mechanism 30 positions about the yaw axis 43 in a spaced-apart relationship to the actuation mechanism 26 of the yaw joint 22a, such that the operator may grasp the actuation lever assembly 100a and reaction lever assembly 100b, one lever assembly in each hand, squeeze the cross member 125 or 127 against the adjacent side 113 or 118 of the hand-levers 114a (shown in Fig. 3a), and draw the lever assemblies 100a and 100b together in a natural, short, arcuate motion which the operator applies in the rotational direction toward which the operator desires that the workpiece 12 or boom assembly 14 translate. The operator then releases his grip on the engagement hand-levers 114a, at which time the actuation mechanism 26 and the reaction mechanism 30 automatically disengage from the cam housing 110 and the reaction hub 120, respectively, thus permitting repositioning of the lever assemblies 100a and 100b. Subsequent engagement enables the repositioning of the boom assembly 14 to continue in a scissor-like fashion. When the boom assembly 14 reaches the desired azimuth or elevation (i.e., it is targeted toward a destination point), the operator releases his grip on the engagement hand-lever 114a, causing the disks 74 and 76 of the torque-limiting mechanism 50a or 52a to engage, thus slowing and eventually stopping the workpiece 12. This permits actuation while minimizing unbalanced reactive forces which tend to dislocate the operator, the result being greater mobility and flexibility in performing maintenance tasks.

Referring again to Fig. 3a and 3b, movement of the side 113 or 118 of the hand-levers 114a or 114b (as shown in Fig. 1b) away from the middle position and

toward the adjacent cross member **125** or **127** causes one of the cables **115** to draw the end **119** toward the respective hand-lever, and thus the end **135** radially inward toward the cam housing **110**, or, as the case may be, the reaction hub **120**. This then engages a spring-biased pin **116** into a divot **118** in the cam housing **110** or the
5 reaction hub **120**, and locks the lever assembly **100a** or **100b** into the cam housing, or the reaction hub **120**.

The cam follower **92** is in a lowest energy state when the cam follower **92** is resting at the bottom of the ramps **104**. In this position, the rotational axis of the cam follower **102** is parallel to the edge **105**, and the disks **74** and **76** are engaged.
10 Relative rotation of the lever assembly **100a** generates a return torque as the cam follower **92**, having rolled up the ramp **104**, and thus having separated the disks **74** and **76** which bias together via the biasing springs **70**, attempts to return to the lowest energy state. This arrangement permits both unlocking and positioning of the boom assembly in one smooth motion.

15 Referring again to Fig. **1a** and **1b**, torque-limiting mechanisms **50a** and **52a** limit the torque input into the pitch and yaw joints **20a** and **22a**, whereby positioning forces which an operator (e.g., a paraplegic, a seated person, an astronaut, or a diver) applies to the end of the boom assembly **14** or the workpiece **12** are effective to reposition the boom assembly **14** when such forces exceed the limits of the torque-
20 limiting mechanisms, thus permitting micro-adjustment of the workpiece at the destination point, and avoiding over-stressing the manipulation device **10**, or the structure **28**.

Referring again to Fig. **2**, the spring rate of the biasing springs **70**, the pre-load of the biasing springs, and the surface area and number of clutch disks **74** and **76**
25 used in the stack **60** determine the torque limits of the torque-limiting mechanisms **50a** and **52b**.

Referring again to Fig. 1a and 1b, the boom assembly 14 includes a boom 130, a housing 132, a rack 134, a mating extension/retraction gear 136, a shaft 140, the crank 124, a counterweight 142 (shown in Fig. 4), and a stop 144 (shown in Fig. 4). The crank 124 and the gear 136 attach to the shaft 140. The gear 136 axially
5 slides between engagement with the rack 134 and a boom extension mechanism (not shown). A channel 146 contains a rack 134 which connects to the counterweight 142, such that movement of the rack causes corresponding movement of the counterweight.

The counterweight 142 slidably mounts to the boom 130. The stop 144 mounts to an end of the boom 130. The operator rotates the crank 124, extending the boom 130
10 to a desired destination point. The engagement mechanism engages the workpiece 12.

The operator locks the boom 130 against further axial movement within the housing 132, and slides the shaft into the housing a pre-determined distance sufficient to disengage the boom extension mechanism (not shown), and engage the rack 134. The operator rotates the crank 124, thus causing the rack 134 to slide within the channel
15 146 (not shown) of the boom 130, and imparting corresponding motion to the counterweight 142. The channel 146 runs parallel to the axis 34. By rotating the crank 132, the operator counterbalances the boom assembly 14 with the workpiece 12, and neutralizes the effects of gravity, thus enabling manipulation of the workpiece in non-neutrally buoyant or non-weightless environments.

20 An advantage of the present invention is that it is simple. This is in part because the manipulation device 10 is manually-driveable. Therefore, few or no electronic components are required.

Another advantage of the present invention is that it securely controls the workpiece 12 to be translated, thus minimizing flailing or other unwanted and often
25 unpredictable oscillation.

Another advantage of the present invention is that the workpiece 12 is

repositionable anywhere in space, within the extension limits of the manipulation device **10**, without first having to spend a substantial amount of time in setting up the manipulation device.

Another advantage of the present invention is that the boom assembly **14** (and
5 therefore also the workpiece **12**) is repositionable about pitch and yaw axes in a convenient fashion. Such is accomplished by first engaging and actuating the lever assembly **100a**, in a natural, short, arcuate motion which the operator applies in the rotational direction toward which the operator desires that the workpiece **12** or boom assembly **14** translate. This permits actuation while minimizing unbalanced reactive
10 forces which tend to dislocate the operator, the result being greater mobility and flexibility in performing maintenance tasks.

Another advantage of the present invention is that micro-adjustment of the workpiece **12** or the end of the boom assembly **14** is permitted at the destination point.

Another advantage of the present invention is that the structure **28**, to which
15 the manipulation device **10** attaches, is protected from large and potentially destructive forces input into the end of the boom assembly **14**.

Another advantage of the present invention is that the lever assemblies **100a**
and **100b** are normally free to rotate about their respective axis until the operator
20 squeezes the hand-lever **114**. This ensures that accidental rotation of the lever through bumping or other contact does not actuate the actuation mechanisms **26**, thus avoiding imparting unwanted and possibly destructive motion-inducing forces to the workpiece **12**.

It is understood that the present invention can take many forms and
25 embodiments. The embodiments shown here illustrate rather than limit the invention.

Others may make variations without departing from the spirit or the scope of the invention, such as that which Fig. **5** depicts.

In Fig. 5, the actuation mechanism associated with each joint **20b** and **22b** is a worm gear drive. In addition to the torque-limiting mechanisms **50b** and **52b**, the pitch and yaw joints **20b** and **22b** each further include a corresponding gear housing **200** and **212**, respectively, and a worm **204** and mating worm gear **206**. In addition,
5 pitch and yaw actuation cranks **216** and **220** attach to the respective worm **204**, such that rotation of the pitch or yaw crank **216** and **220** causes rotation of the corresponding joint **20b** or **22b**.

The pitch and yaw joints **20b** and **22b** each include, respectively: a pitch housing **210** having a torque-limiting mechanism **52b**; and a yaw housing **214** having
10 a torque-limiting mechanism **50b**, which are disposed within each housing. Each torque-limiting mechanism **50b** and **52b** frictionally restrains the boom assembly **14** against free movement, and limits the torque inputs into the structure **28** when an object inadvertently disturbs the manipulation device **10**. Two support arms **199** and **213** extending up from the yaw gear housing **212** form the torsionally-stationary
15 member of the pitch joint **20b**. The upper end **36b** of the stanchion assembly **16b** forms the torsionally-stationary member of the yaw joint **22b**. Retainer pins **219** are disposed in annular grooves **231**, and rotatably retain the yaw gear housing **212** and pitch gear housing **200** onto their respective housing **214** or **210**.

The pitch joint **20b** includes the pitch gear housing **200** which rotatably affixes
20 to the pitch shaft **202**. A bearing **225** mounts between an end of the pitch shaft **202** and the support arm **199**. A bearing cap **229** fastens to the pitch shaft **202**, and retains the bearing **225** in place. The flange **209** of the pitch shaft **202** fastens via fasteners **211** to the support arm **213**. A support arm **207** has an aperture in an end into which the flange **209** of the pitch shaft **202** mounts. A bearing **221** mounts
25 between the flange **209** and the support arm **207**. An opposite end of the support arm **207** rigidly fastens to the pitch gear housing **200**. The worm **204** rotatably mounts on

bearings (not shown) in the pitch gear housing 200. The mating worm gear 206 nonrotatably attaches to a pitch housing 210 via fasteners 215 which fasten to a driving cup 262. The driving cup 262 nonrotatably engages the pitch housing 210 via a key 217. The pitch gear housing 200 houses the mating worm gear 206. Bearings
5 205 support the mating worm gear 206.

As in the preferred embodiment, a torque-limiting clutch disk stack 60 includes alternating first clutch disks 74 having outwardly extending tabs 74' and second clutch disks 76 having inwardly extending tabs 76'. The driving cup 262 rigidly attaches to the pitch housing 210, and includes a relief 80b cut in a sidewall 82b of the driving
10 cup which receives the tabs 74' of the first clutch disks 74. A clutch hub 64 has an external keyway 86 which receives the tabs 76' of the second clutch disks 76. The pressure disk 263 are disposed between the driving cup 262 and the clutch disk stack 60. In a manner similar to that of the preferred embodiment, a pressure plate 256 mounts in the pitch housing 210, and includes a disk-contacting surface 260 adjacent
15 the disk stack 60 and annularly spaced-apart spring-receiving recesses 254. A cover plate 251 affixes to the housing 210, via fasteners 75b, thereby enclosing the torque-limiting mechanism 50b. A bearing 223 mounts between the cover plate 251 and the pitch shaft 202. The cover plate 251 further includes spring-receiving recesses 252 which correspond to those in the pressure plate 256. The key 217 is disposed
20 between the pitch housing 210 and the driving cup 262 within respective keyways 264 and 266 of both the pitch housing 210 and the driving cup 262, thereby preventing relative rotation between the pressure plate and the cover plate, yet permitting limited axial motion. The biasing springs 70 mount within the spring-receiving recesses 252 and 254, between the cover plate 251 and the pressure plate 256, thus exerting
25 pressure on the disks 74 and 76 of the stack 60. The pitch shaft 202 nonrotatably mounts to the clutch hub 64, via a key 270. The yaw joint 22b includes the yaw gear

housing **212** which rotatably affixes to the yaw housing **214**. Bearings **227** and **223** support a yaw shaft **280** in the yaw housing **214**.

Unlike the actuation mechanism **26** of the preferred embodiment, the worm **204** rotatably mounts in the yaw gear housing **212**. The mating worm gear **206** nonrotatably attaches to the yaw housing **214**. The yaw gear housing **212** houses the mating worm gear **206**. The torque-limiting mechanism of the yaw housing **214** is, in functional essentials, the same as that of the pitch housing **210**.

In further embodiments, the worm **204** and worm gear **206** may be double enveloping, thereby reducing contact forces by permitting a larger area of contact between the worm **204** and the worm gear **206**. A suitable double enveloping worm gear pair is "CONE DRIVE" available from Cone Drive Textron, Inc., of Traverse City, Michigan.

In another embodiment, controllable gear motors **208** (shown in phantom) may be used in conjunction with, or as a substitute for, the pitch and yaw actuation cranks **216** and **220**. The controllable gear motors **208** attach to each worm **204**, such that rotation of the controllable gear motors causes rotation of the corresponding joint **20b** or **22b**.

In still further embodiments, a load alleviator **250** alleviates torsional loads about the yaw axis **43**.

The above-described embodiments have many advantages over the prior art. For example, the advantages of the preferred embodiment also apply to the alternate embodiment, with the exception that the operator inputs rotational motion into the crank handles **216** and **220**, rather than more natural, short, arcuate motion in the direction toward which the operator desires that the workpiece **12** or boom assembly **14** move.

Although the illustrative embodiments above describe the invention, a wide

range of modification, change, and substitution is obvious to those of ordinary skill in the art. In some instances, some features of the present invention are independent of other corresponding features. Accordingly, it is appropriate that one construe the appended claims broadly and in a manner consistent with the scope of the invention.

5

Industrial Applicability

In addition to its applicability to workpiece manipulation as depicted in Fig. 4, the manipulation device 10 of the present invention is useful for transferring, repositioning and stowing fixtures, shielding, equipment and/or tools for deep-sea structural maintenance operations on off-shore oil drilling rigs and platforms, or ship
10 hulls. In addition, the torque-limiting mechanism 50a or 52a of the preferred embodiment is useful in antennae or satellite dish structures which may require repositioning in a neutrally buoyant environment or in an environment where it is difficult to react against another fixed structure (e.g. repositionable joints on parabolic dish antennae or telescopes in a field environment in which it may be difficult for the
15 user to otherwise obtain a sure footing, for example, icy or muddy conditions). The actuation mechanism of the preferred embodiment has wide application in joining low speed industrial machinery which require adjustment while the machinery is operating. For example, the sun gear in a planetary gear arrangement may be repositioned while the device is operating through a simple, manual adjustment. The invention may also
20 be used to reposition large power-generating wind mills in a controlled manner.

Abstract of the Disclosure

A device for manipulating a workpiece in space includes a fixture, a stanchion assembly, a manipulation mechanism, an actuation mechanism, and a reaction mechanism. The fixture has an end onto which the workpiece affixes. The stanchion assembly has an upper and a lower end. The manipulation mechanism connects the
30 fixture and the upper end of the stanchion assembly. The lower end of the stanchion assembly mounts, via probe and a socket, to a structure. The actuation mechanism operably connects to the manipulation mechanism, and moves the fixture in space. The reaction mechanism provides a point through which force inputs into the actuation
35 mechanism may react.